NOTES

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A LOW COST DEVICE TO MAKE BIG RIVER CLOSURES

Performance at the Paulo Afonso power project on the São Francisco River

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1. LOCATION - Across the São Francisco river at the Paulo Afonso falls was built a mixed type (wall and gates) dam, 4,300 meters long, crossing several natural channels. During the dry season one of these channels, the main one, carries the entire volume of water, that is, 1,300 m^3/sec. At the site chosen for the dam, the river bed is 120 meters wide and has an average depth of 7 meters, with sections reaching even 14-15 meters. The velocity of the water at the section of greatest flow varies between 3.5 to 4.5 m/sec. After damming the first half of the river, we ran up against current speeds reaching up to 8.5m / sec. in the second half. Due to the above conditions the river bed had to be of solid rock. The river bed is covered with an overburden of large and small boulders mixed with sand and mud, fitting the blocks together.

2. PROBLEM - The first half of the dam was built away from the main channel, without greater problems. Then, due to the above mentioned circumstances, a serious problem arose in the main channel. In view of the importance and the time necessary for the works, the same would be submitted to the worst natural, local conditions, with great changes in discharge with consequent changes in water levels, it was decided, to divert the current, to use the cellular type of cofferdam in steel sheeting piles. This type of cofferdam will resist, as it really did, the great floods of the São Francisco river. The problem, however, was the erection of the cells, due to the depth, irregularities of the bed and specially the velocity of the stream. If we admit a water speed of 4.5 mt/sec., according to DEBUAT's formula, the impact on the cell would be of 300 metric tons. Therefore, we had to build a dam across a river 120 m wide, uneven and rocky bottom, with a minimum discharge volume of 1,300 m^3/sec. and a current velocity varying, according to the circumstances, from 3.5 to 8.5 mt/sec., and a variation of depth ranging from 7 to 14 meters.

3. POSSIBLE SOLUTIONS

a) The most natural way out of the problem would be to build a canal by-passing the working area, thus, diverting the current. But such a canal would have to be cut into the solid rock, be 350 meters long and deep enough to carry easily the water stream, which would mean excavating approximately 300,000 m^3 in volume, that is, more than the amount required for the total excavation for the foundation of the 4,300 m long dam. Two temporary rock-fills, should, the upper one, divert the main stream into the canal, and the lower one, complete the closing and drying of the working area forming the cofferdam.

b) The "crib" solution was also studied, but the "Crib cofferdam", for a positive construction, needs a very detailed knowledge of the river bed profile,

and this was not possible in this particular case due to the local conditions. Neither the sounding nor the echo-bathymetry gave good results in the site. Furthermore, the lumber at the site, in the size and type required, was very costly and therefore very antieconomical.

c) The third solution, which was eventually adopted, consisted of the use of the steel sheeting-piles cells capable, better than any other, to resist the floods that sometimes attain 20,000 m^3/sec. in volume, but normally 10,000 m^3/sec. It had also the advantage of adapting itself well enough to the roughness of the river bed, as will be shown later on, and the possibility to be erected on the site and in a short time, at a reduced cost. Nevertheless, it was possible to complete the erection, only by using two original devices, the description of which is the real purpose of this paper.

4. MODEL - These ideas or tricks were the following: - During the first stage (first half - left bank) a floating caisson was used, generally referred to as "navio" (means "ship" in portuguese) that permitted the erection of the cells in still waters; during the second stage (second half - right bank) a device called "flexible structures" duly rock-filled was used to still the water and allowed the erection of the remaining cells in all safety. Therefore, this operation was of great responsibility not only because it was the key problem of the job, but also because it involved very high expenses. We called upon the scale model laboratory that was located on the site to solve all hydraulics problems that would arise. A glass canal was built, where the discharges, pressures, velocities and even the strains on the structures were measured and controlled. The model of the "navio", its performance, effects, etc., everything was carefully studied with a 40:1 model (linear scale $\lambda = 40$). The similarity laws gave the following ratios: $\sqrt{\lambda}$, $\lambda^{5/2}$, λ^3 respectively for the velocities, discharges and strains. It determined two very important data: the impact strain on the "navio" and the water level raise, once the rock-fill was completed. Figures II, III, IV and V refer to the scale models.

5. EXECUTION - The actual construction work was done in two stages: First, the construction of the threshold and pillars on the left bank. Second, the construction of the works on the right bank.

a) First step - To allow for the erection of the cells, a scale model of a floating "caisson" called "navio" was studied as described above. Firmly anchored, with cables at a point 100 m up stream, the prototype could move so as to be placed in front of the cell to be erected. Once in position, the "navio" was sunk by opening the valves and there it served as a shield, protecting and allowing the erection of the cell. This would have been impossible without this original device, due to the high velocity of the water and its depth. The dislocation of the "navio" was done, transversely, with the help of adequate hoists; and longitudinally with great winches. Once completed the erection of the cell, behind the shield formed by the "navio", it was floated, dislocated and sunk again on the site where the next cell was to be erected. We will not describe here the ways used to erect and launch the "navio". The "navio" was locally built with profiles and steel sheets and weighed roughly 125 tons. Its physical dimensions were: 18 m long, 10 m high and 6 m at its maximum width. A heavy ballast on its bottom held it in the correct position. With such dimensions it allowed for the erection of 7 cells and 1 cell, with diameters of 15.20m and 17.50m, respectively. The layout adopted was the one shown on figure I. The cofferdam was closed at the bank side by a platform-wall built in stone masonry and shaped as a box filled with waste. We will skip, without insisting, over problems regarding infiltration, roughness of the river bed and reduced working space inside the cofferdam. As the cells were erected on the "overburden" the infiltrations were important and the work of excavation, cleaning and concreting was quite hard, but it was executed correctly and in

safety. In fact, the erection work of the cells and of the excavations was accomplished without any serious personal injuries and also without any incidents worth mentioning, in spite of the extremely hard kind of work. During the flood season the work had, evidently, to be suspended, but it did not affect the device. Once the flood wave receded, the pumps emptied the cofferdam and the work was resumed. The cellular system, as expected, functioned perfectly well. Figure III shows the use of the "navio" during the erection of cell no. 4. Once the threshold, pillars and gates were built, we dismantled cells (fig. I) 1, 2, 3, 7 and 8. Then the gates were opened and the river discharge passed on both sides of the "isle" formed by cells 4, 5 and 6, which served then as a working platform. At this point, the works for the second step of the closure were started. It should be noted that all the material from the disassembled "navio" was recuperated and used elsewhere in the works.

b) Second step - As we started to close the river in order to build the second half of the dam (threshold and pillars) right over the thalweg of the river, its flow measured 1,300 m³/sec. It was necessary to erect cells 9, 10 and 11, in order to control the river, and this required the tranquilization of its very rapid flow. Cell no. 12 functioned only as an auxiliary platform. We thought at first of using the "navio" method for this second step, but it was noted that when the last cell was placed the velocity attained 11 m/sec., which would make the anchorage of the "navio" an extremely difficult job. So, it was suggested the adoption of the "obelisk" process, used to close the Saguenay, in Chute Caron, Canada. It consists in building a heavy vertical dam (around 2,500 tons) which has to adapt itself exactly to the irregularities of the river's bottom and has to be thrown suddenly over the river. For this method, two conditions are essential: a solid and large base and the accurate knowledge of the river bed, but both could not be attained. Besides its high cost, the obelisk, when falling, would destroy the "island" which, as has been stated, was formed by cells no. 4, 5 and 6, absolutely necessary for the construction. We then thought about using one or two steel structures, light and flexible, attached to a net and riprapped with man-stones (figure VII). Such structures would be made of frames containing necessary devices in order to be well adapted to the irregularities of the river bed. All this framework would be placed downstream the cells to be erected and would be easily removed after being used. This system was tested on a small scale and proved to be economical, safe, quickly made and efficient. The performance of the model and the prototype were in perfect accordance (see figures X and XI). The two structures consisted of a certain number of trestles forming a very light framework (looking like a cage), whose upright pieces were built with angles welded so as to form a square pipe, and joined together by angles. To this framework we fixed a steel net with 0.20m x 0.20 mesh. The weight of each structure was about 20 tons, so they could be easily moved by the local existing cranes, an important point for the speed of the work. Once in place, the structures were filled with man-stones, as shown in figure VIII. The stones were placed in horizontal layers so as not to create wakes of great speed of water, which is a precaution one has to take in such operations. The height of these flexible structures was 10.5 m and the total gap to be closed was about 44 m. The base of the trestles was 5 m wide. The structure was tied up with 1" steel cables so that it would not be carried down by the water current before the rock-filling operation. As the riprap progressed, the water level increased and its flow was diverted through by-passes constituted by pillars and gates built in the first step. An idea of the placing of the structures and of the rock-filling is given by figure IX. Once the riprap was completed with man-stones weighing 25 to 35 kilos, the flow of water got smooth in the second-half of the river, since the velocity of water corresponded only to the leaking through the stones, which was really very little. The total placing of the steel structures was made in 8 calendar days and the riprap in 9 days. The material used was 40 tons of 3" and 4" angle iron, approximately 6 tons of 1/2" round iron; 1" and 3/4" steel cables, plus 6,000 m³

of man size stone. 25,000 man/hrs were spent for the complete job of setting the structures and the rock-fillings. As this device was located downstream the closing cells, all the material was recuperated, including the stone. It should be mentioned that the entire operations ran according to plans without any disagreeable surprise.

6. COST - Finally, we wish to say a few words on the subject of the cost of the operation. It amounted to US$42,000, including angle irons, nets, labor, stone, hauling charges, miscellaneous, overall expenses, equipments and administration. In these figures the value of the material recuperated was not deducted from the total value. To have a better idea of the smallness of this cost, it is sufficient to say that the cost for closing a gap of 120 m (three times the project described above) on the Columbia river was, according to reports, US$ 1,318,000.

The design and work of the river closure were made, under our direction, by the technical staff of Cia. Hidro Elétrica do São Francisco, owner of the power-plant, in June-July, 1954.

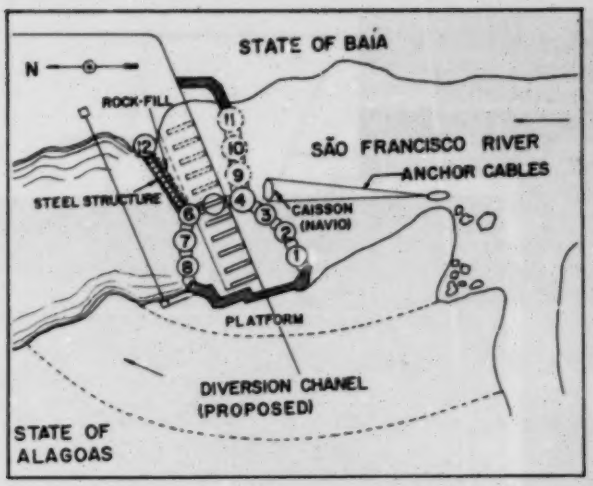

Fig. I - General layout

Fig. 3 - Performance of the "navio" (model)

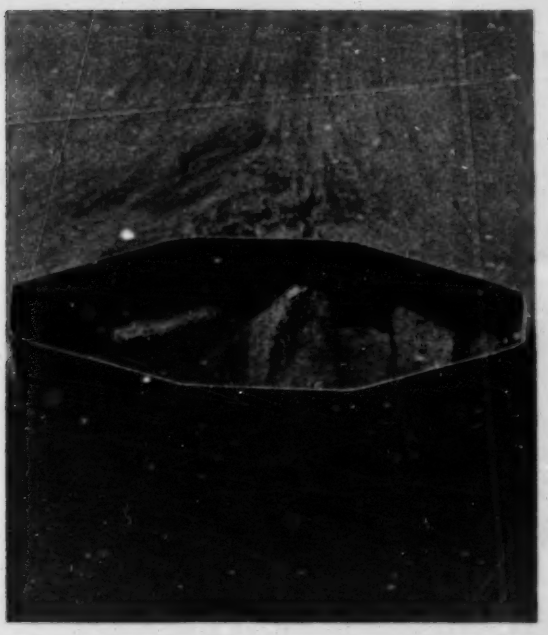

Fig. 2 - Impact on the caisson ("navio") (model)

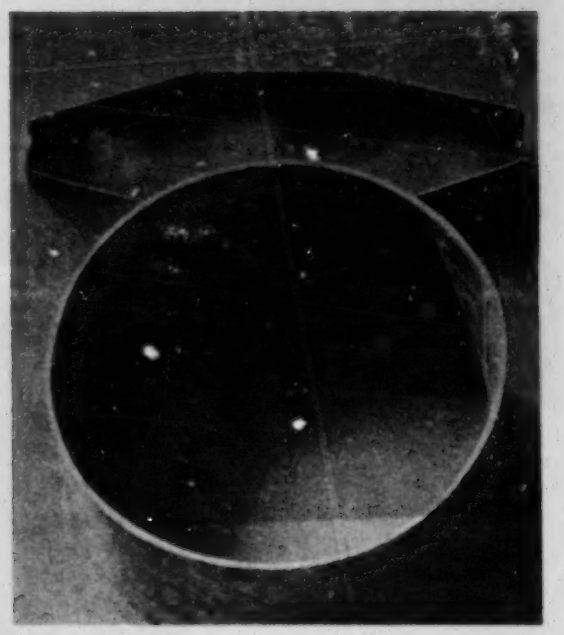

Fig. 4 - The "navio" protecting a cell (model)

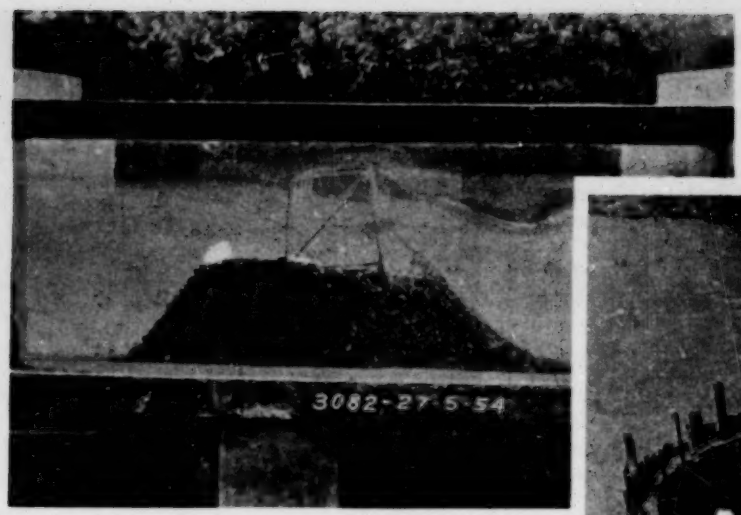

Fig. 5 - Steel-structure and rock-fill (model)

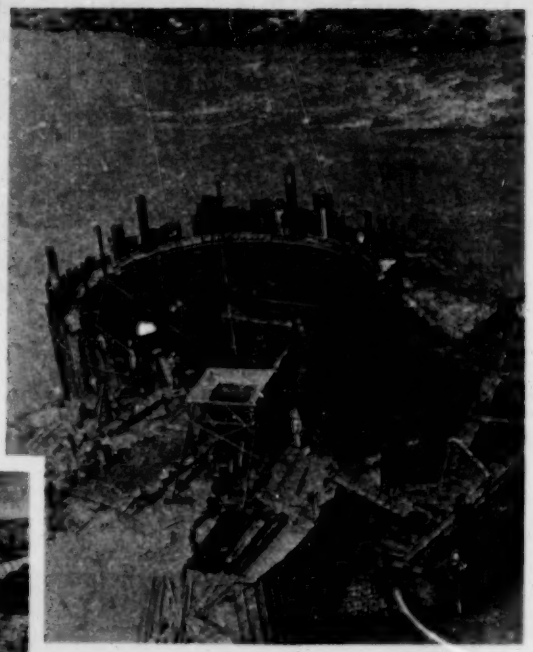

Fig. 6 - Cell no. 4 protected by the "navio" (prototype)

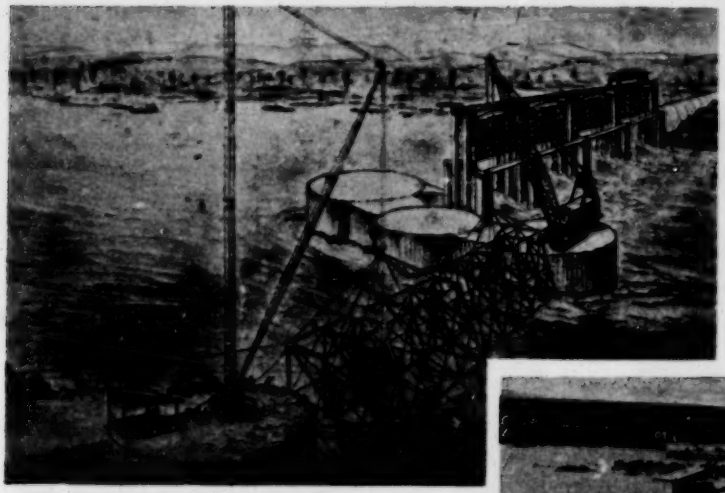

Fig. 7 - "Island" and the structures setting

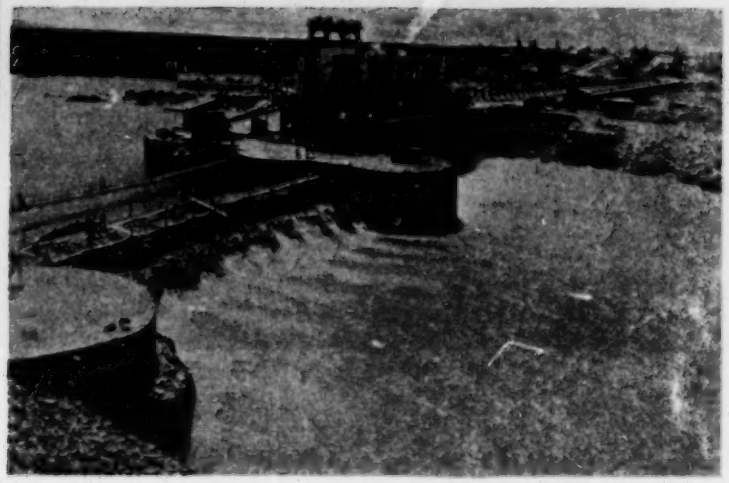

Fig. 8 - Seepage through the rock-fill

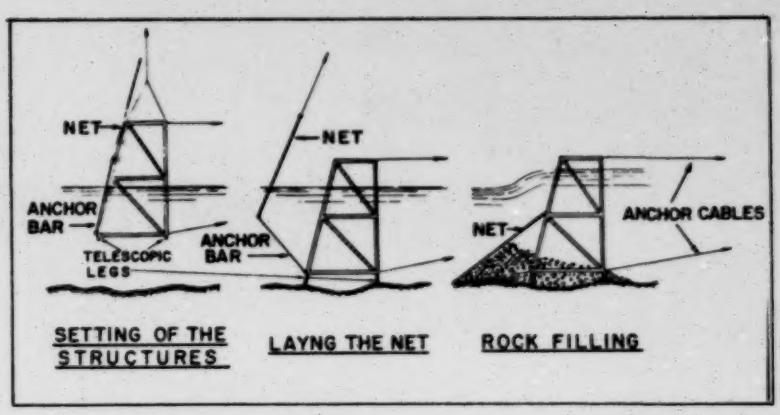

Fig. 9 - Steps of the structures setting

Fig.10 - Rock-fill (model)

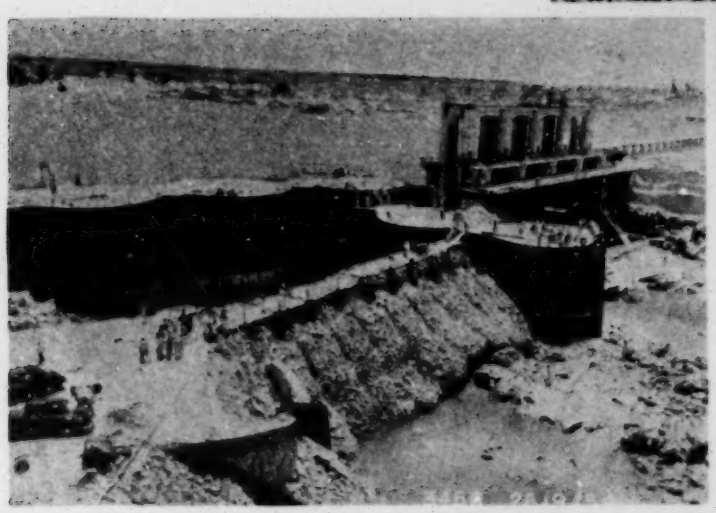

Fig.11 - Rock-fill (prototype)

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